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EDITORIAL

Shoulder biomechanics: today's consensus and tomorrow's perspectives

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Abstract Shoulder biomechanics is a fast growing field, which is progressively expanding its focus to include more applied research. The papers included in this Special Issue confirm this trend. After a classification of the papers as dealing with fundamental or applied research through theoretical or experimental methods, in this Editorial we tried to summarize the elements of consensus and the open issues discussed during the last International Shoulder Group meeting, held in Bologna (Italy) in 2008.

Keywords Shoulder biomechanics · Motion analysis · Musculoskeletal modeling

1 Introduction

The shoulder is a complex structure, consisting of 4 bones (thorax, clavicle, scapula and humerus) and four joints, three anatomical (sternoclavicular, acromioclavicular, glenohumeral) and one functional (scapulothoracic). Contrary to joints in the lower extremity, its stability is mainly ensured by muscles. Through the interplay of these elements, the shoulder ensures to the hand a wide reachable workspace, but it also provides a stable support for fine manipulation tasks [21].

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This balanced compromise between mobility and stability, however, can be easily disturbed if one of the shoulder elements fails, for instance due to repetitive overhead activities, heavy-load tasks or constrained postures [14]. The shoulder (the glenohumeral joint in particular), can thus become painful and instable, and eventually present muscle tears [13]. Given the complexity of the structure, shoulder treatments do not always lead to optimal results, and joint replacement is an option only in case of intolerable pain or reduction of function, fractures or massive muscle tears. Shoulder injury prevention and function restoration are therefore major concerns in clinics, as well as in ergonomics and sport.

To these aims, it is essential to understand how the bony and soft-tissue elements of the shoulder interact among each other, or with an endo-prosthesis, to generate movement, and how they react to internal (e.g., pain) or external (e.g., loads) stimuli. Musculoskeletal modeling and quantitative movement analysis have played an important role in this understanding, and nowadays their role becomes even more important. While in past years the main focus in shoulder biomechanics was on fundamental research with both simulation (theoretical) and experimental activities, in recent years the focus has expanded to include more applied research. This trend is confirmed by the papers included in this Special Issue (Fig. 1), which well represent the 65 abstracts (from 16 Countries) presented at the last International Shoulder Group (ISG) meeting held in Bologna (Italy) in July 2008. Eight of the 12 papers included in the Issue, in fact, dealt with applied research, either using experimental or theoretical methods.

Specifically, experimental methods were used by Coley et al. [5] and Garofalo et al. [7] to test innovative motion analysis protocols suitable for the clinical routine. In

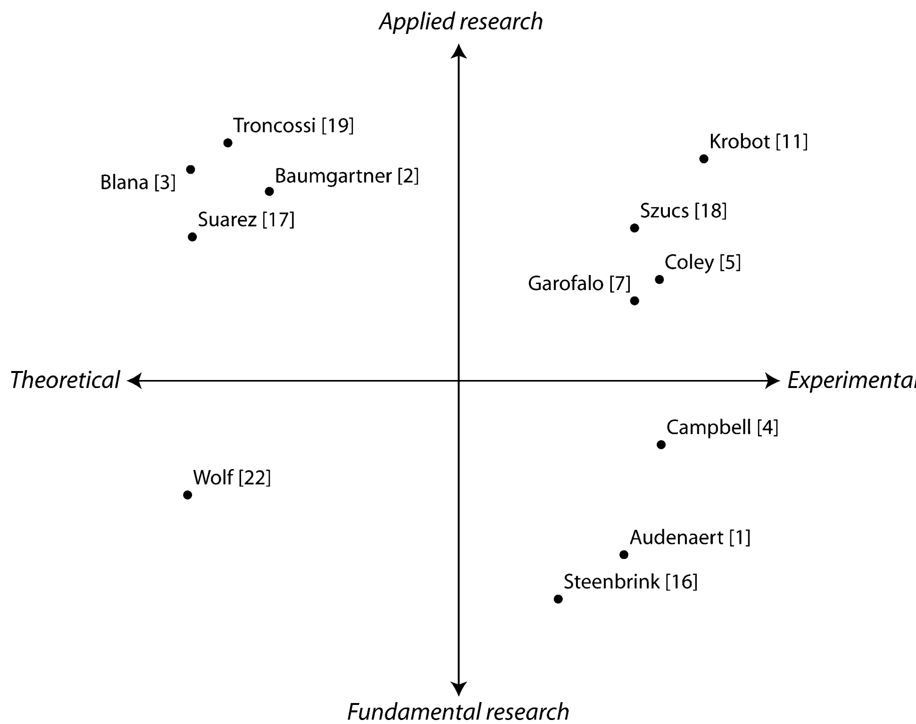

Fig. 1 Classification of the papers included in this Special Issue, based on they addressing fundamental or applied research questions, and using experimental or theoretical (pure mathematical modeling or simulation) methods

particular, Coley tested the application of a gyroscope-based technique to identify and classify the movements of the humerus during 8 h of daily life. This paper is also representative of the new trend in motion analysis to move quantitative studies outside the laboratories and bring them to more friendly environments or even better to the patient's daily life, through fully wearable sensors, similar to the 'Holter registrations' in cardiology. We expect that this innovation will be of major importance, although this will depend on the definition of usable measurement and calibration protocols. To monitor the shoulder-girdle mobility Garofalo identified and tested a 3D motion analysis protocol, which will develop into an easy to use tool able to provide targeted clinical information. Moving further toward clinical questions, Szucs et al. [18] analyzed the relationship between muscle function/fatigue and the development of shoulder pathologies. In their study, through kinematic and EMG analysis, these authors tested the hypothesis that fatigue of the serratus anterior can alter shoulder motion, induce compensation by other shoulder muscles which might then lead to pathology. Where Szucs et al. focused on the effect of function, the study by Krobot et al. [11] dealt with the effect of structure, more specifically with the possible correlation between morphology and the maximum recovery of the stabilization function of the shoulder muscles after impairment, both in asymptomatic individuals and subjects with mild rotator cuff tears. In particular, by assessing 368 subjects they tested the hypothesis that the shape of the shoulder blade is related to the performance of the shoulder muscles.

As for the applied theoretical studies, reports on two categories of modeling techniques were presented. Suarez et al. [17] and Baumgartner et al. [2] used finite element models to analyze the relation between endoprostheses and the surrounding bone. Suarez studied how a degenerated cuff can affect the initial stability of a cementless glenoid implant, while Baumgartner evaluated the quality of a refixation technique in the case of shoulder hemiarthroplasty after proximal humeral head fracture. Troncossi et al. [19] and Blana et al. [3], applied musculoskeletal model simulation studies to two clinical problems, related to high disability impairments: Troncossi applied a theoretical method, kinematic and kinetostatic simulations to define the optimal electromechanical shoulder prosthesis for a bilateral shoulder-disarticulated amputee; Blana presented a Functional Electrical Stimulation controller that uses a combination of feedforward and feedback for arm control in subjects with spinal cord injuries. This latter paper, for the relevance of the topic, the challenge of the task, and the results obtained was appointed with the "ISG–MBEC Young Investigator Best Applied Research Paper Award", sponsored by the Biomedical Engineering Group of the University of Bologna, and Springer Verlag.

Fundamental research studies represented the 1/3 of papers included in the Issue (4/12). Both Campbell et al. [4] and Wolf et al. [22] dealt with problems related to quantitative motion analysis, and in particular to the accuracy of the data acquired through skin mounted sensors, and the presentation of shoulder kinematics to the clinical user. More precisely, Campbell, through an MRI study, gave suggestions about the optimal technical cluster of markers to use to track the position of the glenohumeral joint centre. Wolf, instead, proposed a new method to cope with the so called "Codman paradox", through the definition of a new mathematical formalism. Finally, the studies by Audenaert et al. [1] and Steenbrink et al. [16] dealt with the improvement of current musculoskeletal models, through subject-specific scaling and validation of models predictions against EMG observations. Audenaert tested a new method based on ultra-sound to estimate the volume of triangular-shaped muscles instead of MRI imaging, suitable to customize musculoskeletal models. Steenbrink et al. inspected the effect of external load magnitude on the distribution of shoulder muscle force contributions, both experimentally and using a musculoskeletal model. They showed that some muscles (trapezius pars descendens, deltoideus pars medialis and teres major) did non-linearly scale with external force, indicating the need for testing patients and subjects on equal external force levels. In addition, model simulations showed only small non-linearities that were dependent on the choice of the cost function. Simulation results indicated that, although models have greatly improved, they do not yet appear to produce fully valid individual force results. Based on the attempt to integrate both simulation and experimental approaches and use them for crosswise interpretation and validation, the paper by Steenbrink and co-workers was appointed with the "ISG–MBEC Young Investigator Best Fundamental Research Paper Award", sponsored by the Biomedical Engineering Group of the University of Bologna and Springer Verlag.

From the papers included in the Issue and from the round table held during the last ISG meeting, we can identify some elements of agreement and open issues.

Firstly, there seems to be a consensus on the use of the ISB–ISG recommendations that define (1) the anatomical coordinate systems of the shoulder bones based on the position of specific anatomical landmarks, and (2) how to calculate the shoulder joints kinematics [23], although the choice of the directions for the global coordinate system (x forward, y upward and z to the right) is clearly not ideal for the upper extremity and the 'old' directions (x to the right and z backward) are preferred. At the same time, however, the advent of inertial and magnetic systems able to measure the 3D orientation of their sensors, will require the definition of a second standardization proposal based on joint functional axes, as partially addressed in [6]. These systems, in fact, do not provide information about the position of their sensors in space, and therefore the identification of single, external or internal anatomical landmark is not feasible. The need for a second standardization proposal was generally recognized and the conference meeting decided to form a task group focusing on the further development of such protocol and the definition of a standardization proposal for the use of wearable (inertial) sensors. In the definition of the new proposal, attention should be put to relating the anatomical coordinate systems based on landmarks identification with the new functional anatomical coordinate systems.

Secondly, a standardization of motion analysis protocols beyond the definition of anatomical coordinate system should be searched for. In particular, there seems to be the possibility to define a limited number of standardized protocols addressing questions of comparable content. As a consequence of the discussions during the meeting, a first effort has been made to set a common language for this purpose [10]. In our opinion, a standard protocol should include a clear definition of the (1) clinical questions for which it is suitable, (2) joints and segments of interest, (3) mechanical model assumed for the joints and segments, (4) anatomical and functional coordinate systems, (5) marker-set or sensors placement, (6) set of activities to be performed by the subjects and guidelines for their execution, (7) kinematics optimizations, data processing and presentation.

Thirdly, there seem to be promising experiences coming from the dynamic tracking of the scapula, either with a cluster of markers on the acromion [12, 20] or on a specific support, as described in [9]. However, the general agreement is that quasi-static measurements combined with the use of a scapula locator [8] still are the 'silver' standard ("best available treatment"). Effort should be put in comparing both the quasi-static and the dynamic measurements against a gold standard. Fluoroscopy appears to be a good candidate for a gold standard status.

Finally, the present status in musculoskeletal modeling was discussed. Although the general opinion was that musculoskeletal modeling has taken a great flight and has been and will be of great importance for understanding and quantifying musculoskeletal function, it was also clear that two major issues prevent widespread clinical use. Firstly, the general models available now need to be more thoroughly validated and tested: results by Steenbrink et al. [16] indicated that there is no perfect simulation–experiment match as yet, although new cost functions [15] appear to improve results. Secondly, and also influencing the validation issue, it is quite likely that for clinical purposes models need to be individualized. Whether this is indeed the way to go in musculoskeletal modeling was, however, subject of lively debate. A debate that will certainly be continued in the next ISG meeting, to be held in Minneapolis, summer 2010. If this Special Issue raised your interest in upper extremity biomechanics that is where you should be next summer!

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